The Use of Polystyrene in Lightweight Brick Production

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ABSTRACT

Bricks are widely used in building construction as the most common building materials in Iran. The heavy weight of bricks accounts for the great mass of construction and thus causes more vulnerability against earthquake forces. In the present work, it is, therefore, tried to reduce the density of the bricks, as well as improve thermal insulation properties. Polystyrene foam is one of the substances that is added to the raw materials of bricks, as a pore-forming material. The effect of PSF type and its content in the mix, and also the effect of firing process temperature of the bricks on density, water absorption and compressive strength, are investigated and discussed in this paper.

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Key Words:
polystyrene foam;
lightweight bricks;
thermal insulation;
pore-forming.

INTRODUCTION

Production of lightweight clay bricks and blocks with higher thermal insulation properties is possible by using combustible additives in appropriate amounts and particle sizes. One of the materials used for this purpose is polystyrene foam. Each particle, which is dissipated during firing process and leaves behind a cavity, that can improve thermal insulation properties of the brick. Polystyrene foam is, therefore, used as a pore-forming material in the brick body for reducing thermal conductivity

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and also density of brick which leads to mass reduction of building and improving its resistance to earthquake forces. This is associated with decrease in compressive strength of the bricks. The main problem is how to minimize the loss in strength which accompanies additional porosity of the ceramic body, so as to ensure adequate loadbearing capacity of the bricks [1].

If some plastics are added to the raw materials, it is possible to increase the volume of the voids by controlled procedures. By increasing the volume of the empty spaces, the weight of the bricks is reduced. This causes specific properties, e.g. increased thermal resistance in the end product. Another advantage of lightweight bricks is reduced transportation costs [2].

Making lightweight bricks by polystyrene foam is patented under title “Porotone”, in which polystyrene foam is used to produce large pores[3].

Expanded polystyrene undergoes thermal decomposition at temperatures of 100-700°C without leaving any ashes.The styrene and benzene gases that are liberated in the process escape with the flue gases [3].

Some brick plants use prefoamed polystyrene, but a factory-owned foaming system is essential to mass production. The raw aggregate has a bulk density of approximately 700 kg/m^3 and comes in 125 kg drums or one ton cardboard containers. Styropor P500 is a typical trade name. The drums and cotainers can be stored approximately 6 months and 4 weeks, respectively, without incuring any substantial loss of aerating additives [3].

The raw material is extracted from the feeder by a worm gear and forwarded to proportioner of an intermittent foaming machine. Once inside the foaming machine, the raw aggregate is exposed to saturated steam and constant mixing. This results in formation of minute air-filled balls of styrene with diameters ranging from 0.5 to 3 mm and an average bulk density of 12 kg/m^3. Subsequently, the ready-foamed polystyrene passes through a fluidized bed dryer, where the individual beads are dried and stabilized in a warm-air atmosphere (50-60°C). After passing the dryer, the polystyrene beads are emptied directly into the storage silos or blown into them via injection fans, depending on the location of the dryer. Each storage silo should have a volume of approximately 100 m^3. The number of silos depends on the storage period and daily consumption, whereby a minimum storage period of 24 h should be guaranteed. Next, the polystyrene beads are extracted from the storage silos and passed on to production silos through a pneumatic conveyor system. The production silo is normally installed directly above the double-shaft mixer of the extrusion system. An infinitely variable metering screw is used for drawing the beads out of the silo[3].

Laboratory tests were carried out as part of a research project (Hauck D. and Jung E.) on three brick-making clays of different mineralogical composition, which are used for the production of lightweight bricks and blocks. Combustible materials such as foamed polystyrene were used for coarse pore-forming. With regard to the particle size of foamed polystyrene on the development of strength, it was observed in preliminary tests that reducing the particle diameter from approximately 2.5 mm to 1 mm, assuming the same ceramic body densities, approximately 0.2% higher strengths can be obtained. The exploitation of this effect on a large industrial scale, however, for economic reasons is limited to the use of a mixed grain size, owing to the considerably higher polystyrene consumption with an increase in particle size[4].

In this paper, some results of the research project “production of lightweight bricks using polymeric materials”, carried out at the Building and Housing Research Center is represented.

EXPERIMENTAL

Materials

Soil samples were taken from the Foroun-Abad Mine (23 km off Tehran-Garmsar Road). Chemical tests including: determination of the percentage of Si, Al, Ca, Mg, Fe, Cl, SO_4, loss on ignition at 1000°C, and physical tests including: liquid limit, plastic limit and plasticity index and material finer than No.100 sieve, were carried out on the samples.

The polystyrene foam in two forms of “virgin” and “recycled” types, was used. EPS was supplied by Ayegh Plastic Co., Iran. “Virgin type” was used as received, but “recycled type” used after sieving (3.35 mm sieve).

Procedures

The particle-size distribution tests were carried out for

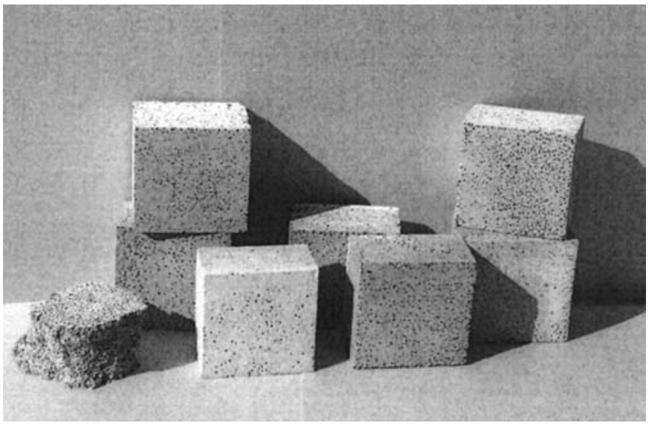

Figure 1. Lightweight brick samples made with PS foam pore forming additive.

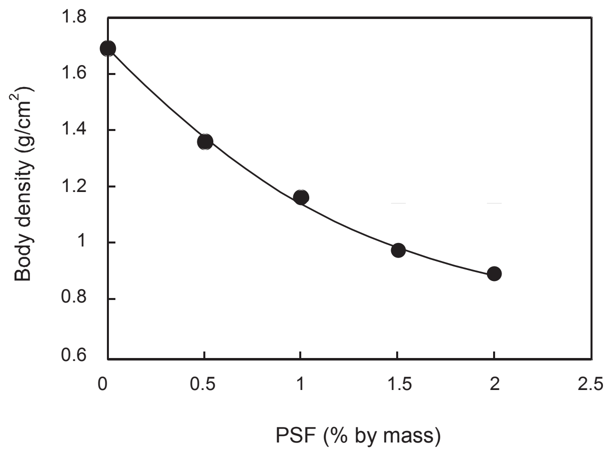

Figure 3. Body density of the brick samples vs. polystyrene foam content.

both forms of EPS. For determination of the best production method, the best mix design and the optimum firing temperature the samples were prepared. The mixture of clay, water and EPS (with different percentages) was mixed in a mixer (Hobart N-500), then compacted in a mould of 70 * 100 * 100 cm dimensions (almost half brick). The samples were remained in the moulds for 3 days under normal conditions. They were taken out of the moulds and were dried out first in laboratory environment and then at 110±5°C in an oven (Ehret type TK/L8). The samples were fired according to the specified temperature-time curves in a furnace (Nabertherm N41/H). Figure 1 shows the lightweight bricks samples made using PS foam additive.

The tests for determination of body density (Archimedes method), drying, firing and total shrinkages, water absorption and compressive strength were carried out on lightweight brick samples. Compressive strength tests were performed with Wykehamfarrance WF556223. The properties were determined according to National Iranian Standard No. 7. The results presented are the average of at least 5 measurements.

Thermal conductivity of lightweight and ordinary brick samples were determined by means of guarded hot plate apparatus (designed and made in BHRC).

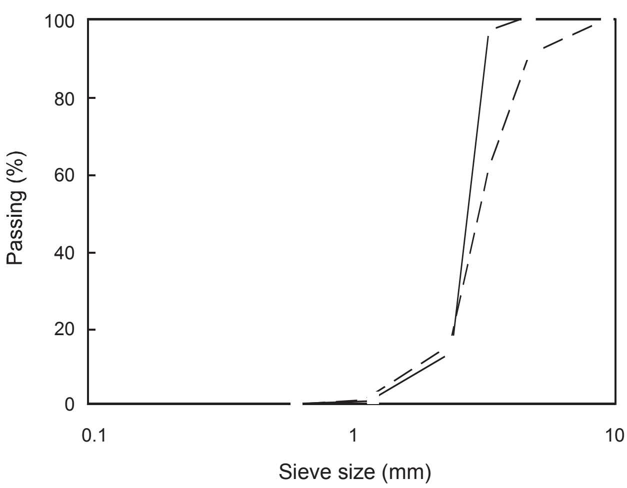

Figure 2. Particle size distribution of virgin and recycled polystyrene foam. —□— recycled PSF; —○— virgin PSF.

RESULTS AND DISCUSSION

The results of chemical tests, Etterberge Limits (LL,PL,PI) and percentage of material retained on No.100 sieve showed that the soil largely consisted of clay (Table 1).

The particle size distribution of foams showed that the diameter of major part of the virgin polystyrene foam particles was between 2-3 mm. The particle size distribution of the recycled polystyrene foam is wider and the particles are larger than the virgin type (Figure 2).

Figure 3 shows that density of the brick samples

Table 1. Etterberge Limits and percentage of material retained on No.100 sieve.

Soil properties	Test results (%)
Plastic limit	17
Liquid limit	30
Plasticity index	13
Retained on No.100 sieve	2.5

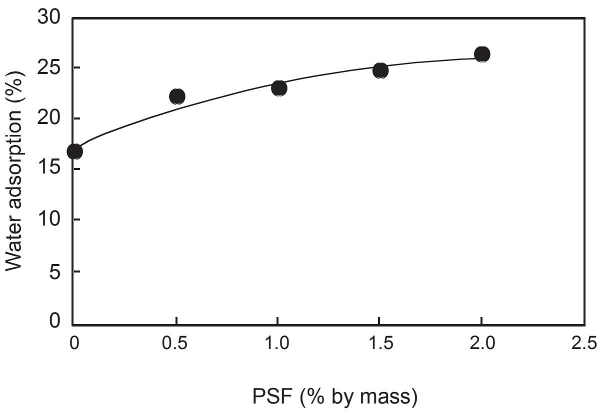

Figure 4. Effect of polystyrene foam content on water absorption of brick samples.

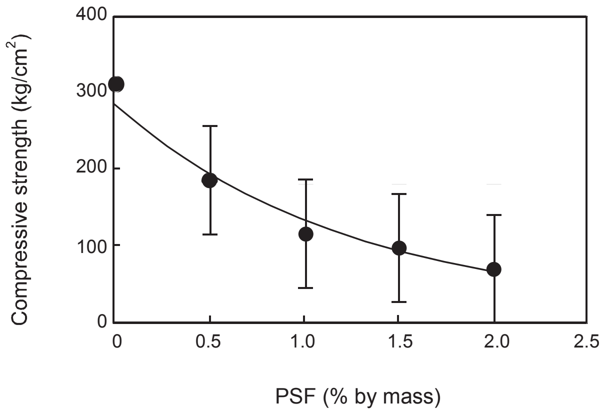

Figure 5. Compressive strength of brick samples vs. polystyrene foam content.

decreases by increasing the polystyrene foam content. With 1.5 percentage of PS foam additive, the density of the brick has reached less than 1 g/cm^3, while the highest percentage of polystyrene foam added to the soil in this work (2%) has decreased the density to about 0.9 g/cm^3.

The best curve fitted on the 5 points obtained by the tests is eqn (1).

$$y = 0.1486x^2 - 0.6891x + 1.6843 \quad (1)$$

Its determination coefficient (R^2) obtained amounts to 0.999.

Figure 4 shows an increase in water absorption by increasing the amount of polystyrene foam.

The relationship between the polystyrene foam content and water absorption is as eqn (2):

$$y = -1.9429x^2 + 8.3657x + 17.229 \quad (2)$$

The determination coefficient of the obtained results is 0.956. Increasing polystyrene content to higher than 0.1%, increases the water absorption so much that this type of bricks cannot be used in facades, and can only be used as virgin internal bricks. It is worth mentioning that the requirement of the Iranian standard for water absorption of facing bricks is 23%, without any specified requirement for the internal ordinary bricks.

Table 2. Compressive strength of brick samples.

EPS (% by mass)	Compressive strength (kg/cm^2)	Standard deviation C.S.
0	309	1.2
0.5	185	1.7
1	115	0.9
1.5	97	1.4
2	69	1.1

In Table 2 and Figure 5 the results of compressive strength tests of brick samples with various weight percentage of polystyrene foam are given. It is noticed from the Figure, as PSF content increases the compressive strength of the bricks decreases on an exponential basis. Eqn (3) gives the best data correlation ($R^2 = 0.970$).

$$y = 278.75e^{-0.7288x} \quad (3)$$

By addition of polystyrene foam to the brick raw materials, the compressive strength of the brick samples should not be reduced less than that specified in the national Iranian standard. Adding even 2% polymer, keeps the compressive strength in a limit that the resulting bricks will be used as loadbearing ordinary bricks because the minimum strength for ordinary bricks in loadbearing walls is 60 kg/cm^2. The content of 2.5% of polystyrene foam corresponds to a compressive strength of 45 kg/cm^2. This strength is more than that specified in the Iranian standard for bricks used in non-loadbearing partition walls (40 kg/cm^2) and, therefore, it is suitable for using in such walls.

Figure 6 shows the effect of body density changes on compressive strength of the brick samples.

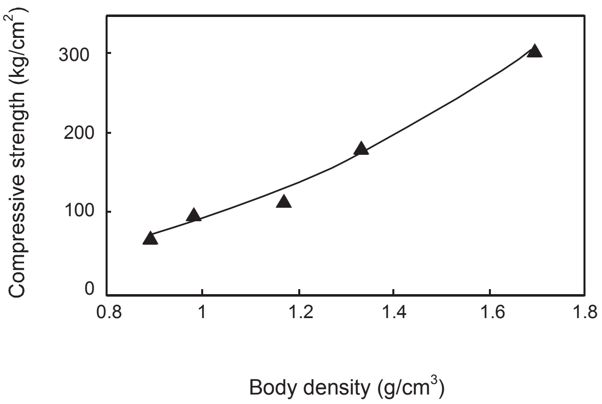

Figure 6. Relationship between the compressive strength and body density in bricks made with different PSF contents.

The relationship between body density and compressive strength is as eqn (4):

$$y = 176.67x^2 - 158.03x + 72.678 \quad (4)$$

Figure 6 shows that with a body density of 1 g/cm^3, compressive strength may reach 90 kg/cm^2 which is quite higher than that of minimum standard limit for the ordinary load-bearing bricks.

The optimum recycled polystyrene foam content for production of lightweight bricks is 1.5wt.%, therefore for determination of the most suitable firing temperature, the samples made with 1.5% recycled PS foam, were fired at 900, 950, 1000 and 1050°C. The tests were performed on these brick samples according to National Iranian Standard No. 7. Results are presented in Table 3.

Figure 7 shows the changes of lightweight brick compressive strength, made with 1.5 % polystyrene foam, vs. the maximum firing temperature. The best fit is as eqn (5).

$$y = 0.0018x^2 - 3.042x + 1335.7 \quad (5)$$

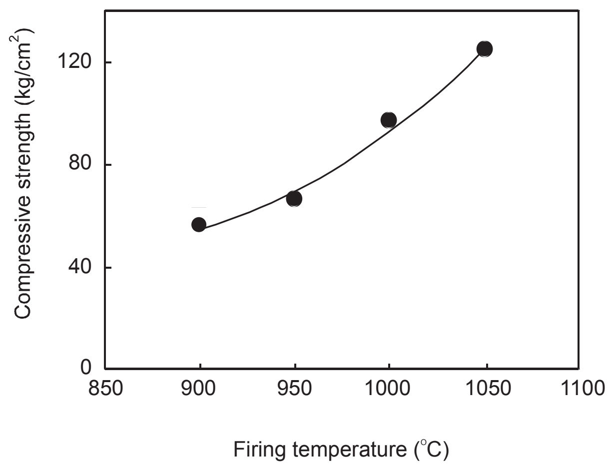

Figure 7. Changes in compressive strength of lightweight brick made by 1.5 wt% polystyrene foam vs. maximum firing temperature.

Determination coefficient (R^2) is equal to 0.990.

As shown in Figure 7, increasing the firing temperature, the compressive strength increases. This is due to formation of new minerals and glass phases, and consequently stronger bondings in the resulting bricks.

In Figure 8, the changes in water absorption of lightweight bricks with 1.5 % polystyrene foam in relation to maximum firing temperature is represented. As it can be seen, the relationship is linear (eqn 6). R^2 is 0.995.

$$y = -0.0508x + 75.98 \quad (6)$$

As considered in Figure 8, increasing firing temperature leads to reduced water absorption. This should be due to formation of voids of closed cells at higher temperatures as a result of formation of glass and new phases like mullite.

In order to study the effect of particle size distribution of polystyrene foam on the properties of lightweight bricks, the brick samples composed of 1.5 %

Table 3. Test results of lightweight brick samples with 1.5% wt. recycled polystyrene foam fired in various temperatures.

Firing temperature (°C)	Body density (g/cm^3)	Water absorption (%by wt)	Compressive strength (kg/cm^2)
900	1.06	30.3	57
950	0.92	27.5	67
1000	0.98	25.5	97
1050	1.05	22.5	125

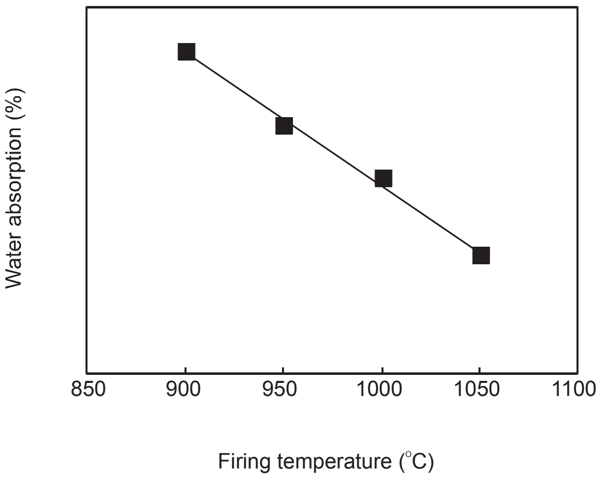

Figure 8. Effect of maximum firing temperature on water absorption of lightweight brick with 1.5 wt.% polystyrene foam additive.

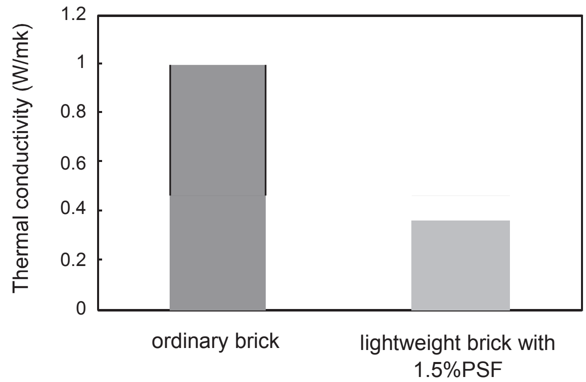

Figure 9. Comparison of thermal conductivity of lightweight bricks with polystyrene foam (1.5 wt. %) and ordinary bricks.

polystyrene foam in form of virgin EPS, recycled EPS and recycled EPS passing 3.35 mm sieve, were fired at 1000°C. The test results are summarized in Table 4.

As seen in Table 4, the water absorption of the lightweight bricks made of recycled polystyrene finer than 3.35 mm sieve is less than those of two others, though the compressive strength of lightweight bricks made of recycled polystyrene foam passed 3.35 mm sieve is much higher than that of the other polystyrene foam types. This is due to lower porosity of this type of brick as a result of its grading. The highest density (0.98 g/cm^3) is related to the lightweight brick made of recycled polystyrene foam passed through 3.35 mm sieve and the lowest density (0.89 g/cm^3) belongs to the lightweight brick made of recycled PSF without seiving.

The thermal conductivity of lightweight bricks made of 1.5% polystyrene foam is 0.24 W/m. K. In Figure 9 this is compared to the thermal conductivity of the ordinary bricks. As it can be seen, there is a great reduction in thermal conductivity of lightweight bricks.

It was aimed within the scope of another research project to establish the technological preconditions for the manufacture of lightweight bricks and blocks using foamed polystyrene as poreforming additive. Therefore, in the next step of the research, lightweight bricks were produced in brick plants and standard tests were performed on them. The results are very promising. The same dryer and kilns can be used as for manufacturing standard masonry bricks. The actual firing process is not influenced by such a low amount of combustible materials, therefore, no special control measures must be taken.

CONCLUSION

Tests showed that by increasing the polystyrene foam additive, the compressive strength and density of the bricks decreases, though the water absorption increases. Therefore, it is necessary to specify the ways for improvement and optimization of clay body so that by reducing the density, the strength of the brick is not reduced considerably. Adding even 2% of recycled polystyrene foam keeps the compressive strength of the resulted bricks as suitable for loadbearing ordinary bricks according to the Iranian standard. Higher firing

Table 4. Test results of water absorption and strength of bricks using 3 types of PS foam.

Type of PSF	Water absorption (%)	Density (g/cm^3)	Compressive strength (kg/cm^2)
Virgin EPS	28.5	0.92	47
Recycled EPS	28.7	0.89	59
Recycled EPS passing 3.35 mm sieve	25.5	0.98	97

temperatures lead to higher compressive strengths and less water absorption. It is due to formation of new minerals like mullite and glass phase, and consequently stronger bondings in the produced bricks. Thermal conductivity of lightweight polymeric bricks made of 1.5% recycled PSF is ¼ of that of ordinary bricks, so it causes a considerable effect on energy saving in building.

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